Can Macro- and Micro-Nutrient Inputs Be Decoupled During Coastal Upwelling?

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LONG-TERM GOAL

Our goal is to understand two fundamental processes that affect surface water clarity in eastern boundary currents such as the California Current: (1) the injection of cold, nutrient-rich waters into the surface, which sustains phytoplankton blooms, and (2) resuspension of sediments by shelf circulation, which increases turbidity. We seek to test the hypothesis that water clarity is not only affected directly by sediment resuspension in coastal upwelling systems, but also indirectly because interaction of upwelling water with shelf sediments adds the micro-nutrient Fe required by phytoplankton.

OBJECTIVES

Our objective is to combine satellite and shipboard data to identify high macro-nutrient/low micro-nutrient water masses in the California Current and to understand the circumstances under which they are formed. This will be accomplished by determining (1) the relation between wind-driven shelf circulation and sediment resuspension, (2) the relation between sediment resuspension and Fe input to upwelling source waters, and (3) the effect of Fe in upwelled waters on the growth of phytoplankton. We will pay particular attention to onshore penetration of "clear" water at depth during upwelling due to the combination of onshore transport and enhanced stratification over the shelf bottom which suppresses mixing of resuspended particles through the water column (Small et al., 1989; Lentz and Trowbridge, 1991)

APPROACH

We focus on a 100 km x 300 km area off the coast of Oregon centered on Cape Blanco (43° N). Repeated hydrographic surveys as well as CZCS imagery have identified a recurrent chlorophyll maximum centered over Heceta Bank at 44° N. More recently, circulation in the area during the upwelling season was studied intensively with SeaSoar, ADCP, and satellite-tracked drifters (Barth et al., in press). In August 1995, surface PCO_2 and macro-nutrients concentrations mapped underway showed a region of strong drawdown by phytoplankton north of Cape Blanco, with little evidence of biological activity to the south, despite comparable wind forcing over the entire region (van Geen et al.,

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in press). To test our hypothesis that this contrast is due to decoupled inputs of macro- and micro-nutrients, we are combining satellite imagery provided by a second generation of instruments (SeaWiFS and, eventually, MODIS) with a ground-truthing cruise conducted in July 1999. We are following the evolution of surface water clarity during the upwelling season in the Cape Blanco region with standard Level-2 SeaWiFS products (chlorophyll *a* concentrations and water turbidity, K490) at 4 km resolution, and will continue to do so over the 1998-2001 period. The interpretation of these observations will be directed by a series of shipboard measurements made during one of Dr. Pat Wheeler's GLOBEC cruises on board RV *Wecoma* on July 4-9, 1999. Cruise participants included PI Lex van Geen, graduate student Zanna Chase (Fe and nutrients), and co-PI John Marra's technician Nicole Ventriello (photosynthetic efficiency).

WORK COMPLETED

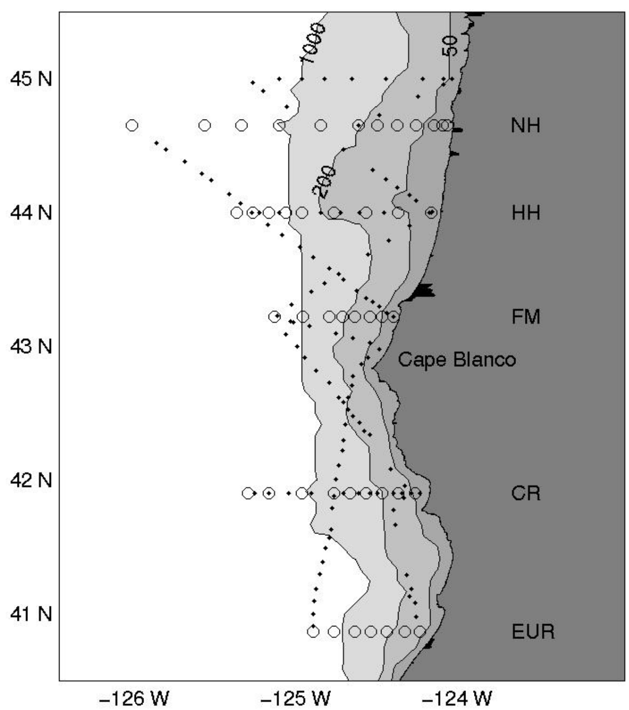

Figure 1. A map of the cruise area along the coast of Oregon. Hydrographic (CTD) stations are indicated by open circles and underway transects are indicated by dots, which represent the location of discrete surface samples collected along the transects. Letters denote GLOBEC transect acronyms.

In preparation for the cruise, we developed a sensitive colorimetric flow-injection system to measure Fe and nitrate concentrations in surface waters while underway. For Fe, the autocatylitic method of Measures et al. 1995 was adapted to a 10-cm flow-through cell of the type used by Waterbury et al. (1997). Underway at ~11 knots, a stream of surface seawater was pumped onboard through all-teflon tubing and into a class-100 flow bench, where it was sampled every 80 seconds for nitrate and iron. This surface-water sampler also allowed us to collect 120 discrete samples along the underway transects (dots, Figure 1). In addition to high resolution surface mapping, we collected 360 Niskin bottle samples at 45 hydrographic stations (open circles, Figure 1) that will allow us to determine three dimensional metal and nutrient fields during the cruise.

We also deployed a Chelsea Instruments Fast Repetition Rate fluorometer (FRRf) in flow-through mode during the entire cruise, acquiring data on photosynthetic efficiency every 15 minutes. Total particulate absorption and chlorophyll *a* were measured on 58 samples, collected underway and from hydrocasts. The latter were used to calibrate the ship's underway fluorometer, and the former will be used in conjunction with the FRRf data to better understand the effect of macro- and/or micro-nutrient limitation.

Since the cruise, we have completed nitrate, phosphate, and silicate analyses on all discrete samples using standard colorimetric methods adapted to flow-injection analysis. The underway nitrate, iron and FRRf data have been reduced, quality-controlled, and merged with the ship's underway data. We have made a preliminary analysis of the overall patterns, and have looked at several interesting transects in detail. We had some clear weather during the cruise and found good SeaWiFS coverage.

RESULTS

Results from an underway transect along the CR line (see Figure 1 for location) are shown in Figure 2 as an example of the type of data collected. Upwelling was vigorous at this latitude, as indicated by SSTs < 10° C which extended ~30 km offshore. Nitrate, iron, and chlorophyll *a* concentrations increased towards shore, reaching 15 μM, 2 nM, and 10 μg/L, respectively. The FFRf parameter, *Fv/Fm*, an indicator of photosynthetic efficiency, was close to its theoretical maximum value of about 0.65, suggesting nearshore phytoplankton were not nutrient stressed. Our data suggest that, within 25 km from the coast, neither macro- nor micro-nutrients were probably rate-limiting at the CR transect.

Of particular interest is the section between 35 and 25 km from the coast along the CR transect. Within this region, surface-water nitrate levels were relatively high (5-10 nM) yet Fe and chlorophyll concentrations were very low (<0.5 nM and <1 μg/L, respectively). These observations, combined with lower *Fv/Fm* ratios, suggest that phytoplankton growth was limited by Fe. This region, and others of similar nature observed at other transects, exactly matches our prediction that particularly strong coastal upwelling can result in elevated surface concentrations of macro-nutrients unaccompanied by the necessary Fe enrichments. Such decoupling could explain why a diatom bloom does not necessarily develop in recently upwelled water, an observation Sverdrup and Allen (1939) already had trouble explaining.

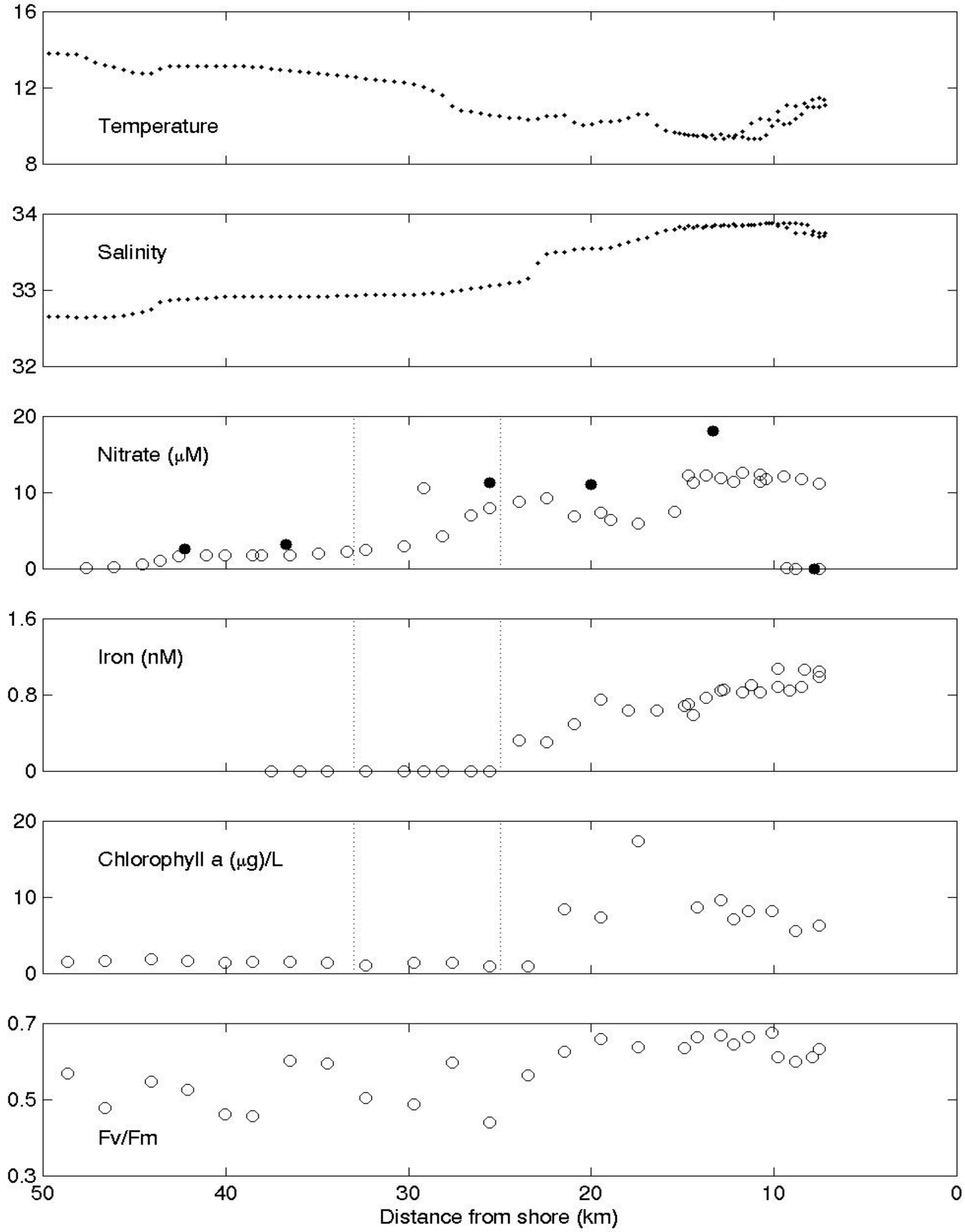

Figure 2. Underway temperature (°C), salinity (psu), nitrate, iron, chlorophyll a and Fv/Fm collected along the 'CR' line at 42.9°N. Filled symbols on the nitrate panel represent concentrations measured post-cruise in discrete (unfiltered) samples collected underway. Vertical dotted lines delimit the region of high nitrate, low chlorophyll.

In contrast to the environment south of Cape Blanco, we found low nitrate concentrations (< 2µM) and high iron concentrations (5-10 nM) near shore at a cross-shelf transect to the north (44° N ;Figure 1: HH). In this region (Heceta Bank) the shelf extends 60 km offshore, chlorophyll is typically high and upwelling relatively weak (SST=13-14°C at the time of sampling). At the time of the cruise however, chlorophyll over the Bank was relatively low (2 µg/L). The contrast between the high Fe observed at this site with a wide shelf, and the low Fe observed further south over a narrow shelf suggests shelf sediments are an important source of Fe input to surface waters. At this latitude, offshore iron concentrations of 15 nM were associated with the low-salinity (28.3), high-silicate (11 µM), low-nitrate (<0.5 µM) plume of the Columbia River, suggesting an additional source of Fe.

IMPACT/APPLICATION

The observation that high nutrient, low chlorophyll regimes exist off of Oregon, as seen off of California (Hutchins et al., 1998), suggests phytoplankton biomass regulation by iron may be a widespread feature of the California Current. Initial results from this study support the suggestion (Johnson et al., 1999) that Fe input to surface waters depends on the interaction of upwelled water with shelf sediments. Future investigations should therefore focus on understanding the link between benthic biogeochemical processes and water column chemistry and biology.

TRANSITIONS

The combination of high resolution macronutrient, iron, and fluorescence measurements proved well suited to the patchy nature of this upwelling system. Our approach should have wide application in understanding the processes that govern phytoplankton productivity and its variability in coastal upwelling systems.

RELATED PROJECTS

The approach and methods developed under the current grant will be applied during two upwelling cruises off the Oregon coast in 2001, and one downwelling cruise in 2003, as part of the recently funded CoOP program "Coastal Advances in Shelf Transport (COAST)" (J. Barth, P. Wheeler, J. Allen, Project Leaders). The LDEO component of this collaborative effort is entitled "Iron Input and Wind-Driven Circulation Along the Oregon Coast".

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